Precision Measurements of Radiative B Meson decay B → Xs gamma with a Semi-inclusive Reconstruction Method

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論 文 内 容 要 旨

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学位論文の 題　　　目	Precision Measurement of Radiative B Meson decay B→Xs gamma with a Semi-inclusive Reconstruction Method (準包括的再構成法を用いた B→Xs gamma の精密測定)		

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論　文　要　旨

1. Introduction

2. Radiative B Meson Decay

In July, 2012, a Higgs boson was observed by the ATLAS and CMS at the Large Hadron Collider(LHC).　The discovery was a remarkable achievement and the sole missing peace in the Standard Model(SM). The SM is very successful theory framework, however leaves some big questions unanswered. These issues lead us to need a new physics(NP) beyond the SM. For the indirect search at the Intensity Frontier which is complementary to the Energy Frontier experiments, such as the LHC, rare processes that are forbidden or suppressed in the SM, but may be enhanced in the NP are significant. In the SM, the radiative B decay, $b \rightarrow s\gamma$, which is a Flavor Changing Neutral Current process, is forbidden at a tree-level and proceeds with loop diagrams. Thus, it has a good sensitivity to a new heavy particle in the loop and is a good probe to the NP.

3. Belle Experiment

In this thesis, we use 711 fb^{-1} data collected by the Belle detector at the KEKB asymmetric e^+e^- collider. The Belle detector has a four-layer silicon vertex detector(SVD), a central drift chamber(CDC), an array of aerogel Cherenkov counters(ACC), time-of-flight(TOF) scintillation counters, and an electromagnetic calorimeter(ECL) of CSI(Tl) crystal located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An instrumented iron flux-return for K_L/μ detection(KLM) is located outside the coil.

4. Monte Carlo(MC) Sample

Two types of signal MC events are generated, one for the K^* region (M_{Xs}<1.15 GeV/c^2) in which the $B \rightarrow X_s\gamma$ transition, where X_s means final states with strangeness=1, proceeds exclusively through $B \rightarrow K^*\gamma$, and one for the inclusive region(M_{Xs}>1.15 GeV/c^2) in which various resonances and non-resonance modes are exist. In the inclusive MC, the M_{Xs} distribution is produced following a Kagan-Neubert model and the light quark pair from X_s is generated and final state hadrons are produced in Pythia. We use M_{Xs} shape which is the best fit one with the previous Belle's result.

5. Reconstruction of $B \rightarrow X_s\gamma$ with a Semi-inclusive Method

We reconstruct the B meson in a high energy photon plus a X_s with a semi-inclusive reconstruction method. In this analysis, the X_s is reconstructed from 38 final states which consists of one or three kaons, at most one η, and at most four pions, of which no more than two can be neutral pions. These modes are covered with 69 % of the X_s decay assuming the isospin asymmetry between K_S and K_L.

The beam-constraint mass is defined as $Mbc = \sqrt{E_{beam}^2 - |\vec{p}_B|^2}$, where E_{beam} and p_B are the beam energy and the momentum of the B meson, respectively, and required to be above 5.24 GeV/c^2.

6. Background Study

The major sources of the background are D meson decay from B decay and $e^+e^- \rightarrow qq$ event.

A lot of background from events with D meson, specifically $B \rightarrow D^{(*)}\rho^+$, remain in the signal region. For suppression of such background, a D meson candidate is reconstructed as a combination of particles used in the X_s reconstruction. The candidate whose D mass is closest to the nominal D mass in an event is vetoed by the mass. Consequently, 90% of the signal is kept, while the background is reduced to 23%.

The largest source of background is qq event. An additional background rejection is ensured by exploiting the difference in the event shape. In BB events both B mesons are produced almost at rest in the Υ(4S) frame and the decay products are distributed isotropically. On the other hand, for qq events, the quarks yield two jets. For an effective background rejection we combine the variables using the neural network(NeuroBayes, NB), which is a highly sophisticated tool for multivariate analysis.

The NB is trained with MC samples which is events with $2.2< M_{Xs} <2.8$ GeV/c^2 to obtain a larger significance in high M_{Xs} region for suppression of the systematic error. As a result, 52 % of the signal keeps, while the qq background reduces to 2 %.

7. Maximum Likelihood Fit

8. Systematic Uncertainties

9. Partial Data Analysis

10. Result

11. Conclusions

We evaluate the signal yield by fitting the M_{bc} distribution with the extended unbinned maximum likelihood. At first, the calibration on the hadronization model in the MC with the data is needed to obtain a correct branching ratio. Fractions of each mode in the MC are compared with them of the data. We calibrate the model by parameters in Pythia and fine-tuning is performed by a direct calibration in which the fractions are reweighed directly.

The M_{bc} fits are performed in each M_{Xs} bin by 0.1 GeV/c^2 to avoid the systematic uncertainty of M_{Xs} shape which is a very large source of the uncertainty. Total branching ratio is calculated by summing the branching ratios in M_{Xs} bins.

We measured the branching fraction for $B \to X_s\gamma$ with a semi-inclusive reconstruction method. The measured branching ratio in M_{Xs} <2.8 GeV/c^2 is

$$\mathrm{BR}(B \to X_s\gamma) = (3.51 \pm 0.17 \pm 0.33) \times 10^{-4}\ (M_{Xs} < 2.8\ \mathrm{GeV/c^2})$$

Extrapolated branching ratio to E_γ >1.6 GeV is

$$\mathrm{BR}(B \to X_s\gamma) = (3.74 \pm 0.18 \pm 0.35) \times 10^{-4}\ (E_\gamma > 1.6\ \mathrm{GeV})$$

This result is in a good agreement with the world averages within 0.4σ and consistent with the SM prediction is 1.3σ. Our result is useful to constraint the NP model beyond the SM. We evaluate a constraint to the two Higgs Doublet Model, and the charged Higgs mass region below 238 GeV/c^2 is excluded at 95% CL.

論文審査の結果の要旨

この研究は、flavor-changing neutral current 崩壊 b→s gamma の分岐比を準包括的再構成法によって精密に測定しようとするものである。準包括的再構成法とは s クォークを含むあらゆる最終状態を再構成することで、b クォークを含まないイベントから来る背景事象を除去するとともに、最終状態が確かに s クォークを含んでいたと云うことを実験的に確認する。他に、崩壊 b→s gamma の分岐比を測定する方法としては、単に光子を検出する方法（包括的再構成）があるが、クォークレベルでの理論計算と比較する際の系統誤差が少ない反面、最終状態が s を含んでいることが確認出来ないという点で、準包括的再構成法が優れている。崩壊 b→s gamma は Belle 実験の物理の中でも最も重要なモードの一つであるが、この解析は Belle 実験の全データを使っており、Belle における準包括的再構成法による崩壊 b→s gamma の分岐比測定の決定版である。また、崩壊 b→s gamma は近い将来走り出す Super KEKB においてももっとも重要なモードと考えられており、この解析の持つ将来的意義も大きい。

より少ないデータによる解析はこの解析以前にも存在したが、斉藤君は準包括的再構成法に使う最終状態の数を約２倍に増やし、また、シグナルを背景事象から分ける方法も neural network をつかって改善した。研究員のガイドを受けながらではあるが、実質上独力で解析を完成した。斉藤君はこれまで多くの国際会議で口頭発表を行って来ており、国際舞台におけるコミュニケーションの能力も充分に持っている。

以上の事柄は、斉藤君が自立して研究活動を行うに必要な高度の研究能力と学識を有することを示しており、この博士論文は，博士（理学）の学位論文として合格と認める